ATMOSPHERIC ENTRY SURVIVAL AND THE POSSIBILITY OF STRATOSPHERIC COLLECTION OF MODERN INTERSTELLAR DUST: George J. Flynn, Dept. of Physics, SUNY-Plattsburgh, 101 Broad Street, Plattsburgh NY 12901, USA.

Taylor et al.[1] detected the ion trails of dust particles, estimated to range from 15 to 45 microns in diameter, entering the Earth's atmosphere with velocities ~100 km/s. Since this velocity significantly exceeds the solar system escape velocity, these particles were identified as interstellar. Taylor et al.[1] observed a seasonal peak in the detected flux, and interpreted this peak to indicate the time of year when the Earth, in its heliocentric orbit, is moving directly towards a stream of incoming interstellar dust, increasing the geocentric velocity of the particles so that particles as small as 15 to 45 microns in diameter produce micrometeors detectable by their radar system[1].

Six months later, when the Earth's heliocentric motion is directly opposite the direction of the interstellar flux, the atmospheric entry velocity of these interstellar grains will be reduced by twice the Earth's orbital velocity and, instead of producing ion trails, some of these interstellar grains may enter the Earth's atmosphere without melting or vaporizing. The peak temperature reached during atmospheric deceleration of these interstellar particles has been modeled, providing the first evidence that, during the season when the Earth is moving away from the interstellar flux, a significant fraction of the ~10 micron diameter interstellar dust should survive Earth atmospheric entry. NASA stratospheric dust collectors flown during this season may already have collected samples of this interstellar dust, and a stratospheric dust collection effort focused on this optimal time window could enhance the collection probability of these interstellar dust particles.

Taylor et al.[1] identified two interstellar dust streams: stream A and stream B. This modeling focuses on the stream A flux, because they estimate the spatial density of particles in stream A is ~10^3 times that in stream B, and the stream A particles have a lower atmospheric entry velocity, giving the stream A particles a significantly higher probability of surviving atmospheric entry. For the stream A particles Taylor et al.[1] infer an atmospheric entry velocity of ~90 km/sec on day 32, when the Earth is moving towards the stream, and they suggest the stream has an inclination of ~30^o to the ecliptic. As the Earth orbits the Sun the atmospheric entry velocity (v) of these stream A particles is given by:

$$v = 64 \text{ km/sec} + [30 \text{ km/s}][\cos(2\pi(t - 32)/365)](\cos i) \quad \text{[Equation 1]}$$

where i is the inclination angle. Thus, the atmospheric entry velocity reaches a minimum of ~38 km/sec on day 215, when the Earth is moving away from the interstellar flux.

The peak temperature reached by a dust particle entering the Earth's atmosphere can be modeled, for any velocity and entry angle, using a method developed by Whipple[2] and extended by Fraundorf[3] to determine the distribution of peak temperatures integrated over all entry angles. Using this method, which correctly predicted that interplanetary dust particles survive atmospheric entry, the distribution of peak temperatures was calculated for particles having an atmospheric entry velocity of 38 km/s. The results are given in Table 1 for 10 micron diameter grains of five particle densities (0.5, 1, 2, 3 and 4 gm/cm^3) spanning the range expected for materials varying from the porous interstellar grains, aggregates of silicates coated by carbonaceous material described by Greenberg and Hage[4], to the compact circumstellar grains which have been extracted from meteorites[5].

For an entry velocity of 38 km/sec, 60% of the 10 micron diameter interstellar dust particles having densities of 1 gm/cm^3, are not heated above 1900 K and more than 1% are not heated above 1200 K. If the interstellar particles have a density as low as 0.5 gm/cm^3, then more than 1% are not heated above 1000 K and 21% are not heated above 1400 K during the season most favorable for survival. Even if the density of the interstellar dust is 3 gm/cc, then 4% of the interstellar particles are not heated above 1900 K. Typical anhydrous silicates, such as olivines and pyroxenes, do not melt until about 1900 K, thus a significant fraction of the interstellar particles composed of these silicates would survive atmospheric entry during the season when the Earth is moving away from the interstellar dust stream. The circumstellar grains extracted from meteorites are typically carbon rich, e.g. diamonds and silicon carbide[5], whose survival temperatures in the Earth's oxygen-rich atmosphere are not known.

The flux of this interstellar dust at Earth cannot be determined from the radar meteor measurements because the stream A particles have an entry velocity of ~90 km/sec, which is below the 100 km/sec cutoff used by Taylor et al.[1] to identify interstellar dust. Thus they reported as interstellar micrometeors only the high-velocity tail of the error distribution of the stream A events, rejecting most of the stream A events (see discussion in Taylor et al.[1]).

Those interstellar grains which enter the atmosphere without melting will settle into the Earth's stratosphere in the same manner as the interplanetary dust particles, which are routinely collected by NASA stratospheric sampling aircraft. Thus, interstellar dust particles in the 5 to 20 micron size range may be present on the NASA stratospheric collection surfaces flown during the favorable collection season. Since the cos(2π (t – 32)/365) term in Eq. 1 varies slowly when the Earth's motion is moving almost directly away from the stream direction, the atmospheric entry velocity of the interstellar dust increases by less than 5% during a two-week period on either side of the optimal (minimum entry velocity) date. Thus, interstellar dust of a size and density allowing survival on the optimal collection date is likely to survive entry over a time window spanning several weeks on either side of the optimum date. Collection efforts focused on the time interval favoring the atmospheric entry survival of interstellar dust particles (and allowing for the time required for these particles to settle from the deceleration altitude to the collection altitude) should enhance the ratio of interstellar to solar system dust on the collection surfaces.

Convincing identification of an individual particle as interstellar would come from detection of a non-solar isotopic composition of either the refractory elements, e.g. O, Si, or the trapped noble gases, both of which have been used to identify the interstellar grains extracted from meteorites[5,6]. However, some interstellar grains are likely to have solar isotopic ratios. Identification of these grains would be more difficult, but might be accomplished by observing the seasonal peaks in the abundance of grains having compositions and structures consistent with astronomical observations of the interstellar grains.

The smaller interstellar grains (~0.5 microns in size) detected by the Ulysses spacecraft[7] also enter the solar system in a stream, and the preceding analysis is applicable to them as well. Modeling by Gufstafson and Lederer[8] indicates that, at least during some parts of the solar cycle, these small interstellar grains penetrate to 1 AU. The atmospheric entry heating of ~0.5 micron grains is more difficult to model because the assumption of an emissivity near 1 is, almost certainly, inappropriate for the ~0.5 micron diameter particles, which are significantly smaller than the wavelength of the radiation they are modeled to emit. However, with entry velocities near 30 km/sec in the most favorable collection season, these particles almost certainly survive atmospheric entry. The present stratospheric dust collectors are believed to collect particles down to only a few microns in size, but redesigned collectors, flown in the appropriate season, should have the capability to collect these ~0.5 micron interstellar grains.

REFERENCES:

1) Taylor, A. D. et al., Nature, 380, 323-325, 1996.
2) Whipple, F. L., Proc. Nat. Acad. Sci. USA, 36, 687-695, 1950
3) Fraundorf, P., Geophys. Res. Lett., 19, 765-768, 1980.
4) Greenberg, J. M. and J. I. Hage, Astrophys. J., 361, 260-274, 1990.
5) Zinner, E., Science, 271, 41-42, 1996.
6) Anders, E. and E. Zinner, Meteoritics, 28, 490, 1993.
7) Grun E. et al., Astron. & Astrophys., 286, 915-924, 1994.
8) Gustafson, B. A. S. and S. M. Lederer, in Physics, Chemistry and Dynamics of Interplanetary Dust, ASP Conf. Series, V 104, 35-38, 1996

Table 1: Peak Temperature Distribution of Interstellar Dust Particles

Particle		**Fraction of Incident Particles Not Heated Above Temperature T**						
Diameter	Density	T<800 K	T<1000K	T<1200K	T<1400K	T<1600K	T<1800K	T<1900K
10 µm	0.5 g/cc	2.4×10^{-3}	1.4×10^{-2}	6.1×10^{-2}	2.1×10^{-1}	6.1×10^{-1}	1.0	1.0
10 µm	1 g/cc	5.6×10^{-4}	3.6×10^{-3}	1.5×10^{-2}	5.2×10^{-2}	1.5×10^{-1}	3.9×10^{-1}	6.0×10^{-1}
10 µm	2 g/cc	1.5×10^{-4}	8.8×10^{-4}	3.8×10^{-3}	1.3×10^{-2}	3.8×10^{-2}	9.7×10^{-2}	1.5×10^{-1}
10 µm	3 g/cc	3.7×10^{-5}	2.2×10^{-4}	9.6×10^{-4}	3.3×10^{-3}	9.5×10^{-3}	2.4×10^{-2}	3.8×10^{-2}
10 µm	4 g/cc	9.3×10^{-6}	5.6×10^{-5}	2.2×10^{-4}	8.2×10^{-4}	2.4×10^{-3}	6.1×10^{-3}	9.4×10^{-3}